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EARTH'S EARLY FOSSIL RECORD: WHY NOT LOOK FOR SIMILAR FOSSILS ON MARS?

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There is general consensus that the early geological history of Mars was similar to that of Earth. If chemical evolution occurred on Mars and life evolved, did evolution follow a pathway similar to that postulated for Earth: heterotrophs appearing first, followed sometime later by autotrophs? Was solar radiation a sufficiently important resource to have favored the development of photoautotrophy? And, even if solar radiation was important, was enough time available for the evolution of this remarkable microbial physiology whose microbial remains and sedimentary constructions appear to have the best chance of being preserved?

The search for the most ancient fossils on Earth has centered on slightly metamorphosed sedimentary rocks in Early Archean terrains. Stromatolites and microfossils, two conventional types of fossils, are actively sought, but so are rocks with potential chemical fossil evidence (kerogen and biologically fractionated isotopes).

To date, the oldest evidence of life on Earth consists of stromatolites, microbial fossils and kerogen that have been found in approximately 3500 Ma-old rocks in Western Australia and South Africa. Carbon of the kerogen is isotopically light with $\delta^{13}\text{C}$ values between -26.6 to -32.0 ‰ for Swaziland (South African) and -31.2 to -34.3 ‰ for Warrawoona (Australian) cherts, suggesting autotrophic activity. Eight morphotypes of microbial fossils (six filamentous and two coccoidal) have been detected in bedded chert from these strata. In terms of their size and shape, these microbial fossils resemble a variety of modern prokaryotes and thus make precise taxonomic assignment very difficult if not impossible. The original chemical composition of the fossils has been so severely altered that biochemical taxonomic procedures standard in microbiology are useless. Nevertheless, the morphology and organization of some of the Warrawoona fossils, e.g., the larger (>3 μm in diameter) tubular and septated filaments and the two pluricellular coccoidal microfossils, are sufficiently similar to some modern cyanobacteria that a taxonomic affiliation with this group seems reasonable. The occurrence of these microbial fossils in stromatolite-like, wavy to irregularly laminated (laminae are 5 to 500 μm thick) chert suggests a microbial mat habit for the organisms and supports the cyanobacterial comparison. However, the overall appearance of the bedded chert in hand specimen does not closely resemble a stratiform stromatolite.

As spectacular as these microbial fossils may be (the preservation of bacteria in rock has always fascinated geologists and biologists), the most impressive and paleobiologically significant fossils are the macroscopic stromatolites found at a few localities in both regions. Stromatolites are organosedimentary structures produced by the sediment trapping, binding and/or precipitation activity of benthic microbes, principally photoautotrophs and usually cyanobacteria. The dynamic interaction of microbes and sediment can produce laminated sedimentary structures that range in geometry from domes and columns centimeters to meters in diameter, to wavy laminated stratiform sediments millimeters to meters in thickness. Stromatolites are found throughout the geological column and are found forming today in a wide variety of environments. The Early Archean stromatolites consist of centimeter-sized domes, pseudocolumns and stratiform constructions which morphologically resemble many younger examples. No microbial fossils have been detected in these stromatolites

but have been found in laminated chert at localities several kilometers away.

Based on our biogeological understanding of stromatolite formation in the past and present, Early Archean stromatolites indicate the following: (1) early in their history, prokaryotes developed an episidimentary to epilithic habit in shallow aqueous environments, some of which were periodically exposed; (2) the microbes actively influenced sediment accumulation at their habitat site; (3) the microbes possessed tropic and/or taxic responsive behavior to the stimulus of sunlight that kept them at or near the sediment-fluid interface; (4) stromatolite-building microbes were probably fast-growing and/or motile (to keep up with sedimentation); (5) the constructing microbes had some minimum resistance to high-energy solar radiation although their sedimentary context and sheaths may have reduced this factor; and (6) communities of several different taxa participated in the construction. The diversity of morphologically complex microbes and the presence of stromatolites in deposits 3500 Ma old indicate that life evolved rapidly on early Earth. If indeed cyanobacteria had evolved by this time (the circumstantial evidence permits such an assumption), this suggests that most, if not all, of the major prokaryotic metabolic pathways had evolved by 3500 Ma ago (if the cyanobacteria were oxygen releasing, then even aerobes could have evolved).

Preservation of the pre-Phanerozoic microbial record is a capricious and selective process. In order for these earliest stromatolites to be fossilized, mineral matter must be precipitated to cement the accumulation of biologically accreted or produced material. This must occur early in the accretion of the stromatolite or early during diagenesis, before the stromatolite undergoes compaction which would alter diagnostic characteristics of its micro- and macrostructure. Calcium carbonate is the most common cementing agent, primarily because the microbes that build stromatolites are photoautotrophs utilizing carbon dioxide and can influence the precipitation of calcium carbonate. At times, chert replaces the carbonate of the stromatolite. Chert can also be a primary chemical sediment. The fossilization of microbes is a much more specialized and variable process. Since microbes do not possess skeletons, it is important that after death, they do not undergo much abiological and biological decomposition. Otherwise, changes can result in shrinkage, decrease in structural integrity and loss of important morphological information. Permineralization of microbes by silica in the form of chert is the best geological phenomenon known for long term preservation (hundreds of millions to billions of years). Calcium carbonate, another geologically readily available cementing and embedding medium, does not form a sufficiently impermeable medium for long term microbial preservation. This is one of the main reasons why stromatolites, which are primarily composed of carbonates, do not normally contain preserved microbes.

If the lessons learned from the study of Earth's earliest fossil record are to be applied to Mars, certain sedimentary rock types and sedimentary rock configurations should be targeted for investigation and returned by the Martian rover and ultimately by human explorers. 1. Domical, columnar to wavy laminated stratiform sedimentary rocks that resemble stromatolites should be actively sought. Limestone, other carbonates and chert are the favored lithology. Being macroscopic, stromatolites might be recognized by an intelligent unmanned rover. 2. Black, waxy chert with conchoidal fracture should be sought. Chert is by far the preferred lithology for the preservation of microbes and chemical fossils. One lesson we have learned from studies of ancient life on Earth is that even under optimal geological conditions (little or no metamorphism, little or no tectonic alteration, excellent outcrops, good black chert) and with experienced field biogeologists, the chances of finding well preserved microbial remains in chert are very low. Serendipity appears to play a major role.